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Developing WQI Method to Assess Surface Water Quality in Ben Tre Province, Vietnam

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Abstract. In this study, the assessment of surface water quality in Ben Tre was conducted based on the province's monitoring data in 2022 and 2023, and the research team conducted additional monitoring in 2024 in 2 seasons (rainy and dry) with 18 parameters: pH, temperature, DO, Turbidity, COD, BOD, TSS, Ammonium, Nitrate, Nitrite, Phosphate, Nickel, Zinc, Iron, Copper, Coliform, E. coli, and total grease. The study typically focused on 5 areas: (1) main river and canal areas; (2) areas flowing through cities and towns; (3) river areas supplying water to water supply plants; (4) surface water in intra-field canals; (5) surface water in lakes. The average WQI calculation results for 6 periods at 53 locations in 2022 were 82-91. In 2023, at 60 locations, the average WQI reached 85-93; in 2024, it was 71-94; all met the purpose of providing domestic water and also needed appropriate treatment measures. From this result, the interpolation map of surface water quality in Ben Tre was established, contributing additional data sources for surface water resource management in the province.

Keywords: WQI, water quality, Vietnam

Introduction

Vietnam is a country with a dense river system with 2,360 rivers over 10 km long, providing about 310 billion m^3 of water /year (Ministry of Natural Resources and Environment, 2007). Water not only provides a living environment but also plays a role in circulation, excretion and reproduction (Baroni et al., 2007), but with the development of society, surface water sources are increasingly polluted and depleted (Kılıç, 2020), water quality does not meet clean water standards. According to statistics from the Ministry of Natural Resources and Environment, 9,000 people/year die and nearly 200,000 people get cancer (Khanh, Vu, & Ngoc, 2023) due to the use of polluted water. In developing countries, 90% of untreated urban wastewater flows into rivers and streams (UNEP International Environment, 2002).

In the world, water quality, pollution levels of rivers, streams, canals, and ditches are assessed through the WQI water quality index which has existed for a long time and is widely applied in the United States, Canada, Europe, India, China, West Asia, Malaysia, etc. (Tuan, Mung, & Cuong, 2017). Abbasi (2002) applied the WQI method to assess water quality based on the appearance or disappearance of some aquatic species; Alobaidy, Abid, and Maulood (2010) assessed water in Dokan Lake, Kurdistan, Iraq; Lumb, Halliwell, and Sharma (2006), studying the Mackenzie - Great Bear sub-basin using the CCME-WQI index, showed that the water source was affected by high turbidity and metals were mostly in particulate form due to high suspended sediment load during the flood season. Bhargava (1983) evaluated the Ganga river water; Das Kangabam et al. (2017) studied Loktak lake water, India, and concluded that Loktak lake water is not suitable for drinking.

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In our country, to assess surface water quality, in addition to analysis for comparison with QCVN standards, the water quality index (WQI) has been widely applied (Tuan, Mung, & Cuong, 2017). Many studies have been conducted in Vietnam such as studying the concentration of some heavy metals in the Red River (Ngoc et al., 2015), in irrigation water used for vegetable cultivation in Thai Nguyen (Duc, 2014), using WQI to monitor water quality of the Cau, Hong - Thai Binh, Nhue - Day river basins of the Northern Environmental Monitoring Center (Northern Environmental Monitoring Center, 2019), assessing the water quality of Cam Son lake in Bac Giang province using the WQI index (Son et al., 2018), using the WQI index to assess surface water quality around pig farm systems in Hanoi (Tra et al., 2016; Son et al., 2019). In recent years, the integration of eutrophication assessment (TSI index), heavy metal pollution concentration (HPI index), biological criteria combined with GIS has also been carried out such as Shiji et al. (2016), assessing water quality through WQI index combined with biological criteria, or combined with GIS tools of Şener, Şener, and Davraz (2017); Hoseinzadeh et al. (2015), combined WQI with river pollution index RPI, water quality index of mountainous forest area FWQI.

Thus, with the conventional assessment method, analyzing water quality and then comparing it with the standards according to QCVN (Vietnamese standard), this assessment method shows whether the water area meets the standards or not, but does not provide an overview of the current status and trends of water quality in the area. In this study, the authors relied on the results of surface water quality monitoring, calculating the WQI index according to Decision No. 1460/QD-TCMT dated November 12, 2019 of the General Department of Environment with groups I, III, IV, V; from there, GIS was applied to create a water quality map for the study area to help managers, policy makers and the community have an overview of water quality in Ben Tre province.

Geologic / Tectonic Setting and Sampling Area

Ben Tre belongs to the Mekong Delta region, formed by An Hoa islet, Bao islet, Minh islet; the province has 1 city and 8 districts with a total natural area of 2,394.8 km^2, population of 1,299,328 people (2023), the total population density of the province is 546 people/km^2 (Ben Tre Provincial Statistics Office, 2024). The average temperature over the years is about 27°C; the highest in May 2000 was 30.3°C; the lowest in January 2014 was 24.1°C. The average rainfall of the province fluctuates from 1,264.0 mm (Binh Dai) to 1,498.2 mm (city). Rainfall in July-November accounts for 80-90% of annual rainfall, while the dry season accounts for only 10-20% but lasts for more than 6 months. This leads to drought, low groundwater levels, acidic soil, and industrial and domestic waste, which leads to land pollution and affects agriculture in the dry season.

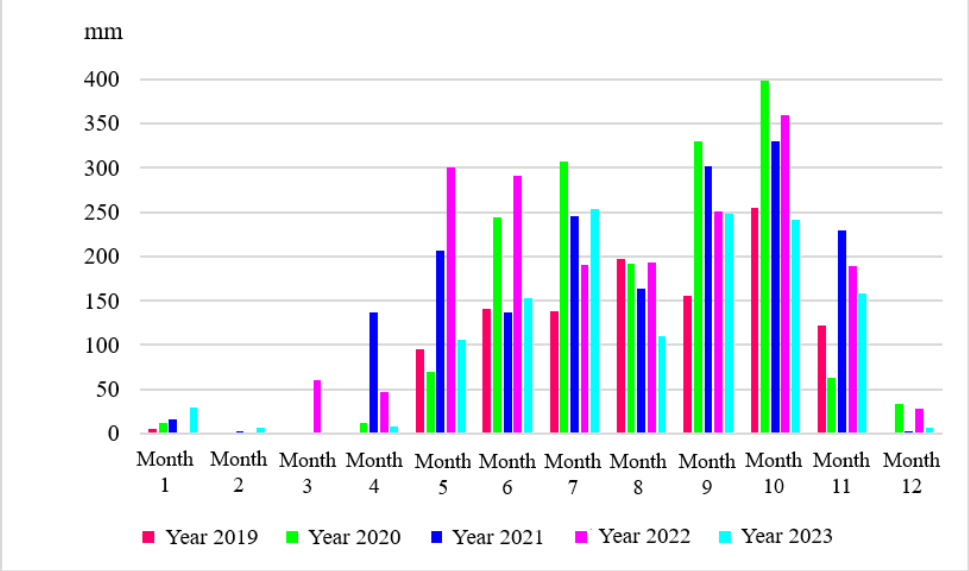

Figure 1Development of total daily rainfall in 2019-2023

Ben Tre has a dense network of rivers and canals with a total length of approximately 6,000 km, a canal density of 6,000 km/2,394.8 km^2 (2.5 km/km^2) with 04 main rivers: My Tho River, Co Chien River, Ham Luong River, Ba Lai River. The province also has 68 main canals with a total length of 363.5 km, level 1 and level 2 canals of 622 km and 2,009 km of level 3 canals in the fields. In addition, there is a system of garden ditches and ponds for people, which is a very important source of water storage during drought and salinity years. The river system has small flows, low flow, flat terrain combined with wave direction perpendicular to the coast, so the tide easily penetrates deep inland.

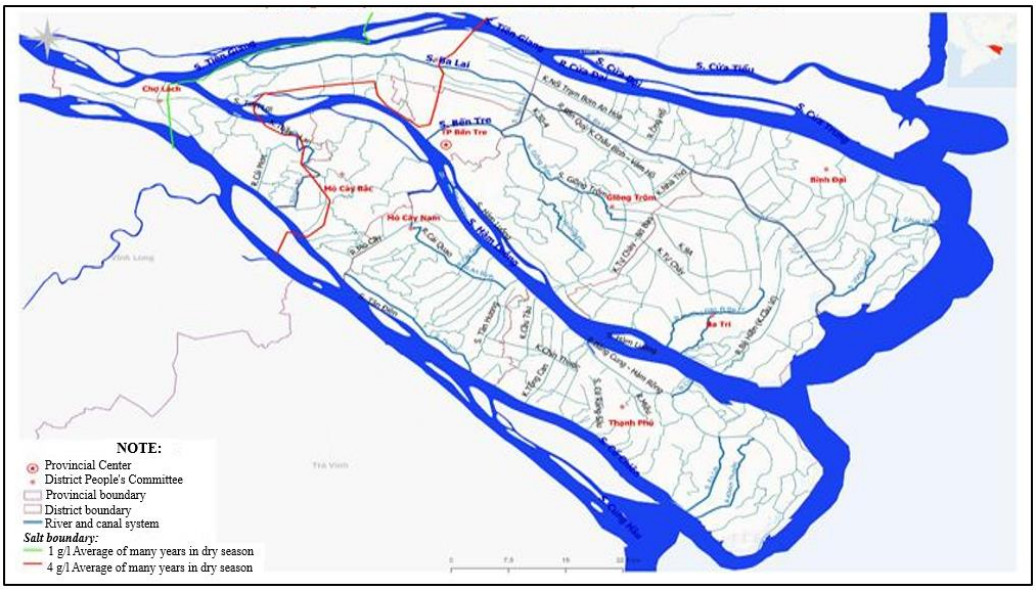

Figure 2Map of the river and canal system in Ben Tre province

The province's economy has always grown every year with the GRDP scale increasing from 51,962 billion VND in 2019 to 68,887 billion VND in 2023 with an average increase of 3,385 billion VND. The structure in 2023 is as follows: Sector I (agriculture, forestry, fishery) accounts for 34.30%; Sector II (industry - construction) 21.33%; Sector III (trade - services) 41.00% and product tax 3.37%.

Data and Method

Survey Methods, Data Collection and Processing

This study conducted field surveys in major river and canal areas; surface water environment flowing through the city and towns; river areas supplying water to water plants; surface water environment of intra-field canals; surface water environment in lakes. Data were collected from 2020 to 2023 at departments and agencies in Ben Tre province and monitoring results of the Center for Research on Technology and Environmental Services in 2024.

Sampling and Analysis Methods

Water samples were collected in 2 seasons of 2024 (rainy season and dry season) and surface water samples were preserved according to TCVN 6663-6:2018, TCVN 6663-3:2016, TCVN 6663-1:2011, TCVN 5994:1995; TCVN 8880:2011. For field measurements (4 parameters): the parameters were measured according to the corresponding methods: pH - TCVN 6492:2011; Temperature - SMEWW 2550B:2017; DO - TCVN 7325:2016; Turbidity - SMEWW 2130B:2017. For laboratory analysis (14 parameters): COD - SMEWW 5220C:2017; BOD - TCVN 6001-1,2:2008; TSS - TCVN 6625:2000; Ammonium (NH_4^+) - SMEWW 4500-NH3.B&F:2017; Nitrate (NO_3^-) - US EPA Method 352.1; Nitrite (NO_2^-) - TCVN 6178:1996; Phosphate (PO_4^{3-}) - TCVN 6202:2008; Ni - SMEWW 3113B:2017; Zn, Fe, Cu - SMEWW 3111B:2017; Coliform, E.coli - TCVN 6187-2:2020; Total oil, grease - SMEWW 5520B:2017.

Method of Calculating Water Quality Index WQI

To calculate the WQI index, this study applied Decision No. 1460/QD-TCMT dated November 12, 2019 of the General Department of Environment [2] - Decision 1460:

For the parameters As, Pb, BOD_5, COD, $N\text{-}NH_4$, $N\text{-}NO_3$, $N\text{-}NO_2$, $P\text{-}PO_4$, Coliform, calculate according to the following formula:

$$WQI_{SI} = \frac{q_i - q_{i+1}}{BP_{i+1} - BP_i}(BP_{i+1} - C_P) + q_{i+1} \quad (1)$$

In there:

BP_i: Lower limit concentration of the monitoring parameter value specified in Table 1 corresponding to level i

BP_{i+1}: Upper limit concentration of the monitored parameter value specified in Table 1 corresponding to level i+1

q_i: WQI value at level i given in the table corresponding to *BP* value $_i$

q_{i+1}: WQI value at level i+1 given in the table corresponds to BP value $_{i+1}$

C_p: Value of the observed parameter to be taken into account.

Table 1Surface water monitoring locations in 2024 in Ben Tre province

Symbol	Dry season	Rainy season	Y	X	Location	Symbol	Dry season	Rainy season	Y	X	Location
NM01	NM.120 324.001	NM.090 824.002	565614	1130341	Ham Luong Ferry Terminal	NM13	NM.130 324.002	NM.080 824.006	596562	1119052	Kenh Lap Lake - Phuoc Ngai Commune
NM02	NM.120 324.002	NM.090 824.003	567194	1131608	Golden Gate Bridge	NM14	NM.130 324.003	NM.080 824.005	594275	1114329	Lac Dia Lake - Phu Le Commune
NM03	NM.120 324.003	NM.090 824.005	568360	1131208	An Thuan Bridge	NM15	NM.130 324.004	NM.080 824.004	591847	1112848	Ba Tri Self-flowing Canal - An Binh Tay Commune
NM04	NM.120 324.004	NM.090 824.004	568512	1134974	Truc Giang Lake	NM16	NM.130 324.005	NM.080 824.003	578658	1104689	Women Channel
NM05	NM.120 324.005	NM.090 824.001	565835	1134974	River supplying water to Shandong water plant	NM17	NM.130 324.006	NM.080 824.001	583479	1100222	Thanh Phu District Reservoir
NM06	NM.120 324.006	NM.080 824.010	566216	1138477	Ba Lai Bridge	NM18	NM.130 324.007	NM.080 824.002	584816	1093483	Camp Wharf
NM07	NM.120 324.007	NM.060 824.001	565614	1130340	Rach Mieu Ferry	NM19	NM.130 324.008	NM.070 824.007	563439	1120479	Mo Cay Nam town river
NM08	NM.120 324.008	NM.070 824.003	564404	1132214	Ham Luong River	NM20	NM.140 324.001	NM.070 824.004	559296	1128371	Ong Tao Bridge
NM09	NM.120 324.009	NM.080 824.009	551678	1137634	River supplying water to An Hiep water plant	NM21	NM.140 324.002	NM.070 824.005	540453	1135748	Cho Lach Canal
NM10	NM.120 324.010	NM.060 824.008	579447	1128266	Luong Quoi Commune Water Supply Plant	NM22	NM.140 324.003	NM.070 824.006	540872	1136709	Cho Lach District Water Treatment Plant
NM11	NM.120 324.011	NM.060 824.009	579470	1128221	Intra-field canal of Luong Quoi commune	NM23	NM.140 324.004	NM.060 824.002	567194	1131608	Giao Long Industrial Park internal canal
NM12	NM.130 324.001	NM.060 824.003	582068	1133555	Chau Hung commune intra-field canal	NM24	NM.120 324.012	NM.060 824.004	594397	1132335	Ben Cat

Source: Center for Research on Technology and Environmental Services, 2024

Table 2Qi and BPi values for parameters evaluated in Ben Tre province

i	q_i	$_i$ value specified for each parameter								
		BOD_5	COD	Cu	$N\text{-}_{NH4}$	$N\text{-}NO_3$	$N\text{-}NO_2$	$P\text{-}PO_4$	Coliform	E. coli
				mg/L					MPN/100 mL	
1	**100**	≤4	≤ 10	≤ 0.1	< 0.3	≤ 2	≤ 0.05	≤ 0.1	≤ 2,500	≤ 20
2	**75**	6	15	0.2	0.3	5	-	0.2	5,000	50
3	**50**	15	30	0.5	0.6	10	-	0.3	7,500	100
4	**25**	25	50	1.0	0.9	15	-	0.5	10,000	200
5	**10**	≥50	≥ 150	≥ 2	≥ 5	≥ 15	≥ 0.05	≥ 4	>10,000	>200

For DO parameter (WQI_{DO}): calculated through DO% saturation value.

- Calculate saturated DO value:

$$DO_{bão\ hòa} = 14{,}652 - 0{,}41022T + 0{,}0079910T^2 - 0{,}000077774T^3$$

T: water environment temperature at the time of observation (unit: °C).

- Calculate DO % saturation value:

$$DO_{\%\ saturate} = \frac{DO_{dissolved}}{DO_{saturate}} * 100$$

$DO_{Dissolved}$: Observed DO value (unit: mg/l)

DO_{DO} value

In which: + Cp: DO % saturation value;

+ BPi , BP_{i+1} , q_i , q_{i+1} are the values corresponding to levels i, i+1 in Table 2 specifying the values of BP_i and q_i for $DO_{\%\ saturation}$;

$$WQI_{SI} = \frac{q_{i+1} - q_i}{BP_{i+1} - BP_i}(C_P - BP_i) + q_i \quad (2)$$

Table 3 i and q_i values for saturated DO%

i	1	2	3	4	5	6	7	8	9	10
BP_i	<20	20	50	75	88	112	125	150	200	>200
q_i	10	25	50	75	100	100	75	50	25	10

If $DO_{\%\ saturation}$ < 20 or $DO_{\%\ saturation}$ > 200, then WQI_{DO} = 10.

If 20 < $DO_{\%\ saturation}$ value < 88, then WQI_{DO} is calculated by formula (2) and using Table 2.

If 88 ≤ $DO_{\%\ saturation}$ ≤ 112, then WQI_{DO} = 100.

If 112 < $DO_{\%\ saturation}$ < 200, then WQI_{DO} Calculate by formula 1 and use the Table to specify BP_i and q_i values for $DO_{\%\ saturation}$.

* For pH parameters:

Table 4 i and q_i values for pH parameters

i	1	2	3	4	5	6
BP_i	< 5.5	5.5	6	8.5	9	> 9
q_i	10	50	100	100	50	10

If the pH value is < 5.5 or pH > 9, then WQI_{pH} = 10.

If 5.5 < pH < 6, then WQI_{pH} is calculated using formula 2 and using Table 3.

If 6 ≤ pH ≤ 8.5, then WQI_{pH} = 100.

If 8.5 < pH < 9, then the pH WQI is calculated using formula (1) and using the Table specifying BPi and q_i values for the pH parameter.

Calculating WQI for Ben Tre province: after calculating WQI for each parameter, WQI is calculated according to the formula:

$$WQI = \frac{WQI_I}{100} \times \frac{[\prod_{i=1}^{n} WQI_{II}]^{I/n}}{100} \times \frac{[\prod_{i=1}^{m} WQI_{III}]^{I/m}}{100} \times \left[\frac{1}{7}\sum_{i=1}^{7} WQI_{IV} \times WQI_V\right]^{1/2} \quad (3)$$

In there:

WQI_I: Calculation result for pH parameter.

WQI_{II}: Calculation results for parameters Aldrin, BHC, Dieldrin, DDTs, Heptachlor & Heptachlorepoxide (Group II, not included in the calculation because Ben Tre water body is not mainly affected by pesticide pollution)

WQI_{III}: Calculation results for As, Pb parameters.

WQI_{IV}: Calculation results for parameters DO, BOD_5, COD, $N\text{-}NH_4$, $N\text{-}NO_3$, NNO_2, $P\text{-}PO_4$.

WQI v: Calculation results for Coliform parameter.

The calculated WQI value will be rounded to an integer.

From there, compare the WQI with the water quality assessment level table. After calculating the WQI result, use the table to determine the WQI value corresponding to the comparison level, assess the water quality:

Table 5Water quality assessment level according to WQI index

WQI value range	Water quality	Fit for purpose	Color
91 - 100	Very good	Good for domestic water supply purposes	Blue
76 - 90	Good	Used for domestic water supply purposes but requires appropriate treatment measures	Green
51 - 75	Medium	Used for irrigation and other similar purposes	Yellow
26 - 50	Least	Used for navigation and other similar purposes	Orange
10 - 25	Heavy pollution	Heavily polluted water, need treatment measures in the future	Red
< 10	Very heavy pollution	Water is contaminated, need to have measures to fix and handle	Brown

GIS Technology Method

GIS (Geographic Information Systems) method, ArcGIS software (version 10.8.2) is applied to build information based on separating objects with the same properties into the same group called data layers, from which to build attribute information and location shapes in real space based on 3 simple geometric types: points, lines, and areas. Based on that rule, basic data layers will be built including boundary layers, rivers, and monitoring locations on the river. After being built, the data layers will be overlaid to create thematic maps showing distribution information about local boundaries and water quality monitoring points. Data layers are also used to analyze the distribution of WQI index.

Results & Discussion

Industrial and agricultural production activities and river water in Ben Tre province are being polluted. Waste from factories, workshops, production facilities, as well as from rural areas flowing into the river causes water pollution, affecting human health and living organisms in the water environment. Based on the technical instructions for calculating and publishing the Vietnam Water Quality Index (VN-WQI) according to Decision 1460/QD-TCMT dated November 12, 2019 of the General Department of Environment, this study will be based on the results of surface water quality analysis in the province in 2022, 2023 (Department of Natural Resources and Environment, 2022, 2023; Ben Tre Provincial People's Committee, 2023; Department of Natural Resources and Environment of Ben Tre province, 2020; General Department of Environment, 2019) and the monitoring results of the ETC Center in 2024, from which to calculate and evaluate the surface water quality in Ben Tre.

Surface Water Quality in Ben Tre Province in 2022

The authors inherited periodic monitoring data in the province to assess surface water quality, with 53 sampling locations, 6 monitoring periods, analyzing the parameters: pH, Temperature, DO, TSS, Fe, NH_4^+, NO_3^-, BOD_5, COD, Coliform, Salinity, Turbidity, PO_4^{3-}

(Department of Natural Resources and Environment, 2022, 2023), and compared QCVN 08-MT:2023/BTNMT. The analysis results showed that the parameters all met type A, B in most locations.

But in some locations, in some monitoring periods, there are some parameters that reach type C, such as the DO content of the water quality of rivers and canals flowing through the towns and cities of Ben Tre, fluctuating from 3.39 to 7.64 mg/l, at the location of Binh Nguyen Canal (period 4), Airport Bridge (period 3) is quite low due to the influence of rain and low tide. For the Fe parameter, most locations exceed the allowable limit of the standard (QCVN 08-MT: 2023/BTNMT) fluctuating from 0.160 to 3.440 mg/l. For Ammonium (NH_4^+) in periods 5 and 6, both exceed the standard, such as in Binh Nguyen Canal, period 6 exceeds 5.13 times, period 5 exceeds 4.63 times because the area is currently stagnant and domestic wastewater is discharged into it. With BOD_5 all positions are at level C and D ranging from 7.4-27.99 mg/L.

Based on the analysis results, the VN-WQI index calculation in 2022 for locations ranging from 78 to 96 is at good and very good levels. In the river and canal areas flowing through urban areas and aquaculture, the WQI is only at an average level; in the area within Ben Tre province, the WQI is at good and very good levels.

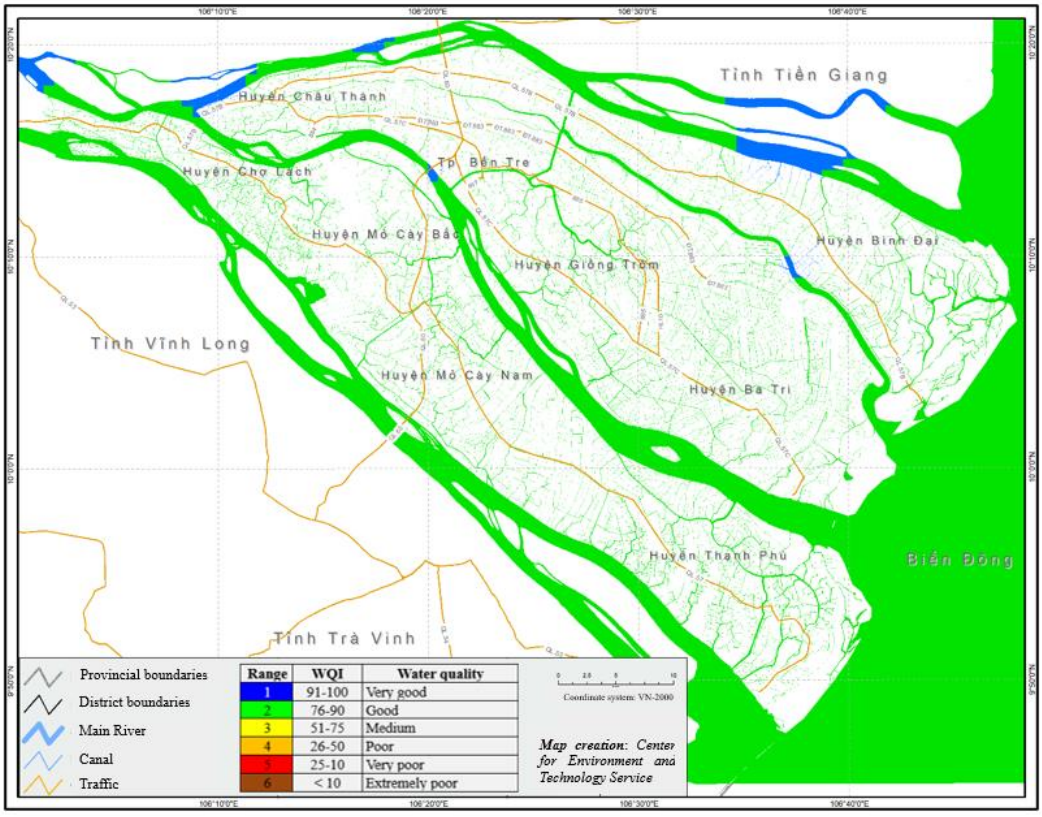

Figure 3Map of WQI index zoning in 2022 in Ben Tre province

Surface Water Quality in Ben Tre Province in 2023

As in 2022, for 2023, the group of authors inherited periodic monitoring data in the province to assess surface water quality, with 60 sampling locations, 6 monitoring periods, analyzing the parameters: pH, Temperature, DO, TSS, Fe, NH_4^+, NO_3^-, NO_2^-, BOD_5, COD, Coliform, Salinity, PO_4^{3-}, E.coli, total oil, grease (Department of Natural Resources and Environment, 2022, 2023, and compared QCVN 08-MT: 2023/BTNMT. The analysis results showed that the parameters all met type A, B in most locations.

However, at some locations, in some monitoring periods, some parameters reached type C, D, exceeding QCVN 08-MT:2023/BTNMT; such as the Fe parameter at the monitoring points had values > 0.5 mg/L, all exceeding the maximum value. With Nitrite (NO_2^-) in the Cai Lon bridge area, Thom river, Tan Huong culvert all exceeded the standard, the value fluctuated from 0.06-0.12 mg/L; in the river, canal, and port areas, the value was 0.06-0.13, exceeding the standard due to waterway vehicles entering and leaving the port, and seafood purchasing and processing facilities in the fishing port area. With BOD_5, the result reached type D with a large content > 10 mg/L due to aquaculture activities, food processing, waterway vehicles, and seafood purchasing and processing facilities.

Based on the analysis results, the calculation of the VN-WQI index in 2023 for locations ranging from 71-94, most locations are at good and very good levels; some locations only reach average levels such as at Ba Lai dam phase 2 (WQI=72), Cai Quao river (WQI=75), Giong Trom town river, Ba Tri town river phase 2-5 with results ranging from 71-75; Thuy San ferry phase 2, 3 only reached 73-75; at Binh Phu commune, Phu An Hoa reached an average level of 73, 75; Luong Quoi commune phase 2 is 74, phase 3 is 72, phase 4 is 71, Tan Thuy commune phase 5 is 75.

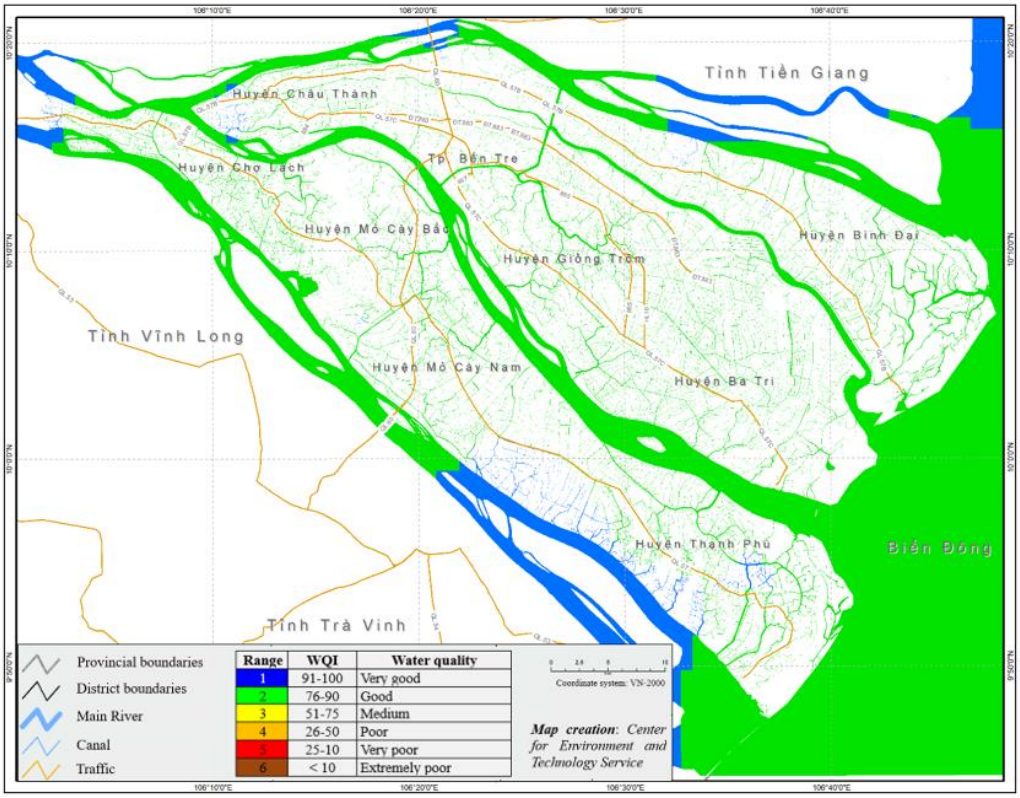

Figure 4Map of WQI index zoning in 2023 in Ben Tre province

Surface Water Quality in Ben Tre Province in 2024

To assess the surface water quality in Ben Tre province in 2024, the authors conducted monitoring and collected additional surface water samples at locations (Table 1) outside the annual surface water monitoring network to have a more objective basis for comparison. The test results showed that 11/18 parameters for monitoring surface water quality in the main rivers and canals in Ben Tre province were within the allowable limits according to QCVN 08:2023/BTNMT; the monitoring parameters exceeding the allowable standard limits include: COD, BOD5, TSS, Ammonium, Nitrite, Nickel, Iron. COD in both seasons was 1.31-5.52 times higher than the allowable standard, of which the highest was surface water at Ben Trai

in the dry season at 82.8 mg/L; BOD $_5$ is 1.13-6.30 times higher than the allowable standard, the highest is surface water at Ben Trai in the dry season at 37.8 mg/L; TSS is 1.62-4.71 times higher than the allowable standard, the highest is surface water at Ham Luong River in the dry season at 471.0 mg/L, especially surface water at Ben Trai in both seasons is within the allowable threshold; Amoni at Rach Mieu ferry in the rainy season is 1.5 times higher than the allowable standard; Nickel is 4.4-25.3 times higher than the allowable standard, the highest is surface water at Ben Trai in the dry season at 2.53 mg/L; Iron at Ham Luong River in the rainy season exceeds the allowable standard by 1.12 times.

Based on this result, calculating WQI, the surface water quality of this area at 2 sampling periods in the dry season and rainy season is mostly at good and very good levels (Figure 5). At Rach Mieu ferry, the water quality (WQI) at 2 monitoring periods in the rainy season and dry season is both at good levels, fluctuating between 88-89, Ham Luong ferry: 82-91, Ham Luong river: 79-90, Trai wharf: 77-86, Cat wharf: 86-89.

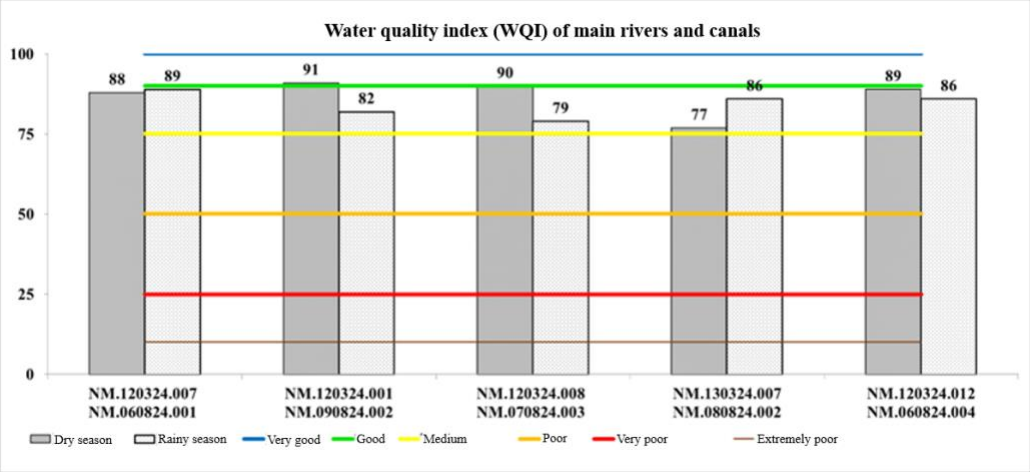

Figure 5rivers and canals in Ben Tre province in 2024

For the surface water flowing through the city and towns, the test results showed that 10/18 monitoring parameters were within the allowable limits according to the standards, the monitoring parameters exceeded the allowable limits: COD, BOD $_5$, TSS, Ammonium, Nitrite, Phosphate, Nickel, Iron. COD in both seasons was 1.21-5.63 times higher than the allowable standards, the highest was the surface water at Mo Cay Nam town river in the dry season at 84.4 mg/L; BOD $_5$ exceeded the allowable standards by 1.41-6.47 times, the highest was at Mo Cay Nam town river in the dry season at 38.8 mg/L; TSS at Ba Lai bridge in the dry season exceeded the allowable standards by 1.48 times (148.4 mg/L); Ammonium is 1.37-3.30 times higher than the allowable standard in the dry season at Ba Lai bridge, An Thuan bridge and Kien Vang bridge, the highest is the surface water at Kien Vang bridge (0.99 mg/L); Nitrite is 1.16-8.40 times higher than the allowable standard, the highest is the surface water at Ba Lai bridge in the rainy season at 0.42 mg/L, and in the dry season at Ba Lai bridge, An Thuan bridge, Cho Lach river, Mo Cay Nam river, the water quality meets the standard; Phosphate in Mo Cay Nam town river in the dry season is 1.83 times higher than the allowable standard, reaching 0.55 mg/L; Nickel is 6.20-21.60 times higher than the allowable standard, the highest is the surface water at Mo Cay Nam town river in the dry season at 1.02 mg/L; Iron concentration in Mo Cay Nam town river in the rainy season is 1.26 times higher than the allowable standard, reaching 0.63 mg/L.

The results of calculating WQI in this area are all at good and very good levels (Figure 6). At Ba Lai Bridge, Chau Thanh, WQI in both the rainy and dry seasons is at a good level, ranging from 83-89; at An Thuan Bridge, Ben Tre City, WQI is from 85-93; at Kien Vang

Bridge, the water quality is quite good in the rainy season with WQI of 81, but in the dry season it is only average at 74; at Mo Cay town river it is 79-84.

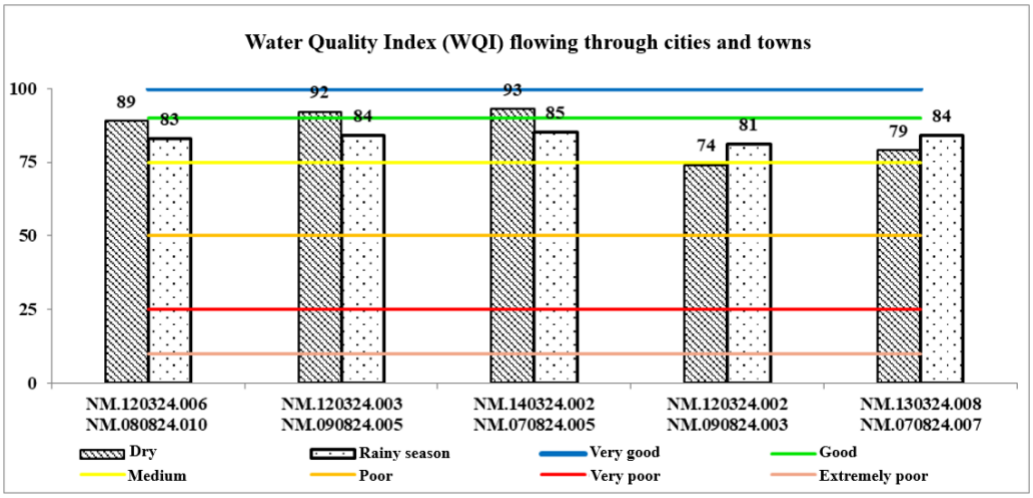

Figure 6flowing through cities and towns in Ben Tre in 2024

For surface water in the river area supplying water to water plants, the test results show that 11/18 monitoring parameters are within the allowable limits according to QCVN 08:2023/BTNMT; the monitoring parameters exceeding the allowable limits include: COD, BOD5, TSS, Ammonium, Nitrite, Phosphate, Nickel. COD concentration is 1.63-2.83 times higher than the allowable standard, at the river supplying water to Son Dong plant in the rainy season it is 42.5 mg/L but at An Hiep water plant it meets the allowable standard; BOD5 is 1.01-3.32 times higher than the allowable standard, the highest is surface water at the river supplying water to Son Dong plant in the rainy season at 19.9 mg/L; TSS is 1.15 times higher than the standard; Ammonium exceeded the standard by 1.5-5.7 times, the highest was at the river supplying water to the Son Dong factory in the rainy season at 1.7 mg/L; Nitrite had 37.5% of the data higher than the allowable standard by 1.6-9.4 times, the highest was at the river supplying water to the Son Dong factory in the rainy season at 0.47 mg/L; Phosphate at Cho Lach water plant in the dry season was 1.37 times higher than the standard; Nickel at all monitoring points exceeded the allowable standard during the dry season sampling, higher than the allowable standard by 3.4-13.6 times, the highest was at the river supplying water to the Son Dong factory in the dry season at 1.36 mg/L.

From the monitoring results, the authors calculated the WQI index at 2 sampling periods in the dry season and the rainy season, most of which were at good and very good levels (Figure 7), specifically at An Hiep water supply plant, the WQI was very good, ranging from 93-94; at Son Dong plant, it was 64-87, but in the rainy season, it was only average; at Luong Quoi - Giong Trom water supply plant, the WQI was around 81-88; at Cho Lach water plant, it was 84-89.

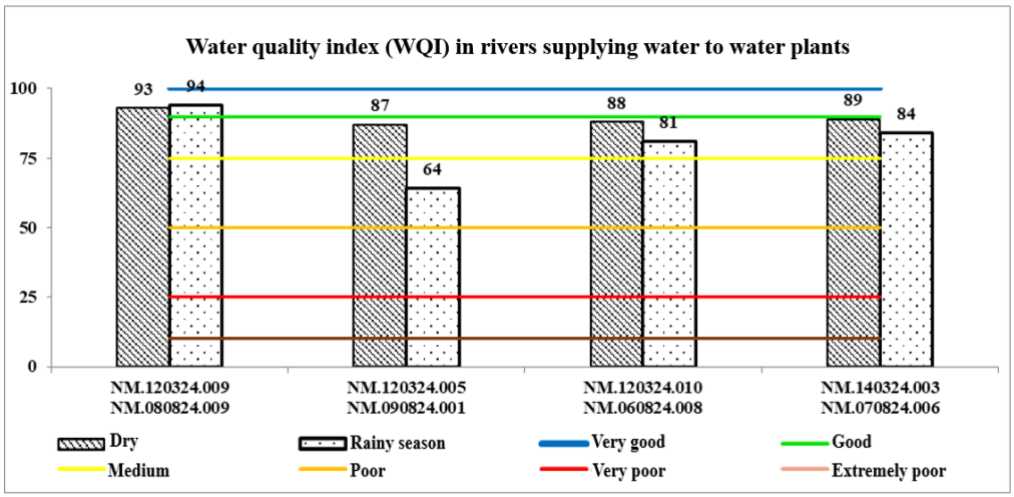

Figure 7water plants in Ben Tre in 2024

For surface water of the intra-field canal, 13/18 monitoring parameters are within the allowable limits according to the standards; while COD, BOD $_5$, Ammonium, Nitrite, and Nickel exceed the allowable limits. Specifically, COD and BOD $_5$ at 06/06 monitoring points in the 2 sample seasons all exceeded, of which COD exceeded from 1.09 - 3.42 times, BOD $_5$ exceeded 1.05-4.60 times, the highest was at Phu Nu canal in the dry season, specifically COD was 51.3 mg/L and BOD $_5$ was 27.6 mg/L; Ammonium at the intra-field canal of Luong Quoi commune and Tu Chay canal in the dry season, surface water at Ong Tao bridge and the intra-field canal of Giao Long Industrial Park in the rainy season exceeded the standards from 1.2-2.5 times, the highest at the intra-field canal of Giao Long Industrial Park in the rainy season was 0.75 mg/L; Nitrite has 41.7% of the data higher than the allowable standard from 1.4-36.6 times , the highest at Ong Tao bridge in the rainy season is 1.83 mg/L; Nickel has 58.3% of the data higher than the allowable standard from 1.5-43.0 times, the highest at Phu Nu canal in the dry season is 4.30 mg/L.

From the monitoring results, the calculated WQI shows that the surface water quality of the intra-field canals at the two sampling periods in the dry and rainy seasons are both at a good level (Figure 8); in which the surface water at Ong Tao bridge fluctuates from 78-90, the intra-field canal of Luong Quoi commune is 79-84, the intra-field canal of Chau Hung commune is 88, the intra-field canal of Giao Long Industrial Park is from 81-86, at Tu Chay and Ba Tri canals is 82-87, at Phu Nu canal is 80-82.

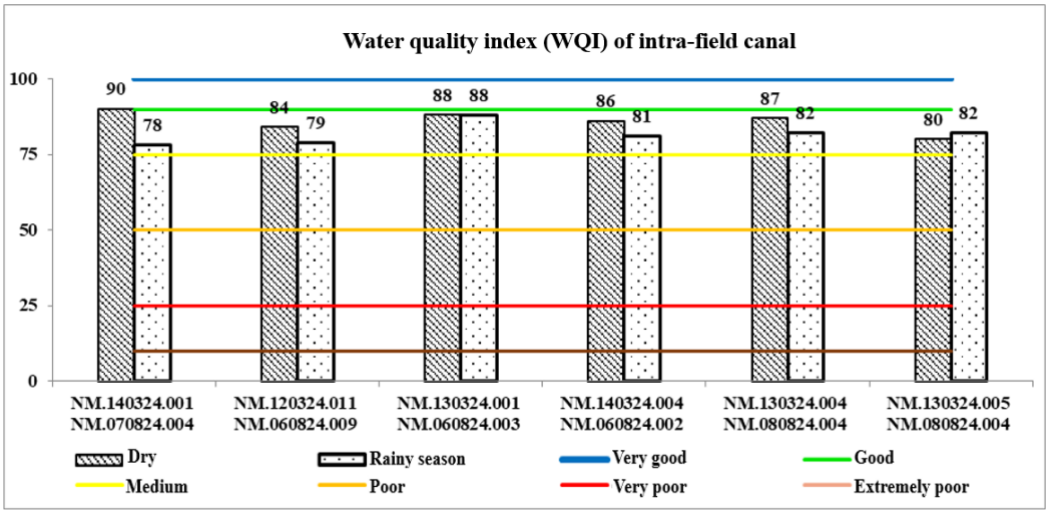

Figure 8in intra-field canals in Ben Tre province in 2024

For surface water in Ben Tre province's lakes, the test results show that 12/18 parameters of surface water quality monitoring in the area flowing through the city and towns are within the allowable limits according to standards, while COD, BOD5, Ammonium, Nitrite, Phosphate, Nickel exceed the allowable limits. COD and BOD5 at 04/04 monitoring points in the 2 autumn sampling seasons all exceeded the standards, in which COD exceeded 1.63-7.51 times, BOD5 exceeded 1.93-8.88 times, the highest was at Thanh Phu freshwater reservoir in the rainy season, specifically COD was 112.7 mg/L and BOD5 was 53.3 mg/L; Ammonium at Truc Giang lake in the dry season was 1.13 times higher; Nitrite had 42.9% of the data higher than the allowable standards from 1.2-3.6 times; Phosphate at Lac Dia Lake in the dry season is 1.83 times higher; Nickel has 62.5% of the data higher than the allowable standard from 1.9-18.2 times, the highest at Thanh Phu freshwater reservoir in the dry season is 1.82 mg/L.

Through the test results, WQI calculation shows that the water quality of the lakes of the province in the two sampling periods in the dry and rainy seasons is at an average level (12.5%) to good (87.5%) (Figure 9); in which Thanh Phu freshwater reservoir WQI for both seasons fluctuates from 77-81, Kenh Lap lake is 84-87, Lac Dia lake is at a good level in the rainy season (WQI=84) and at an average level in the dry season (WQI=71), Truc Giang lake reaches 85-89.

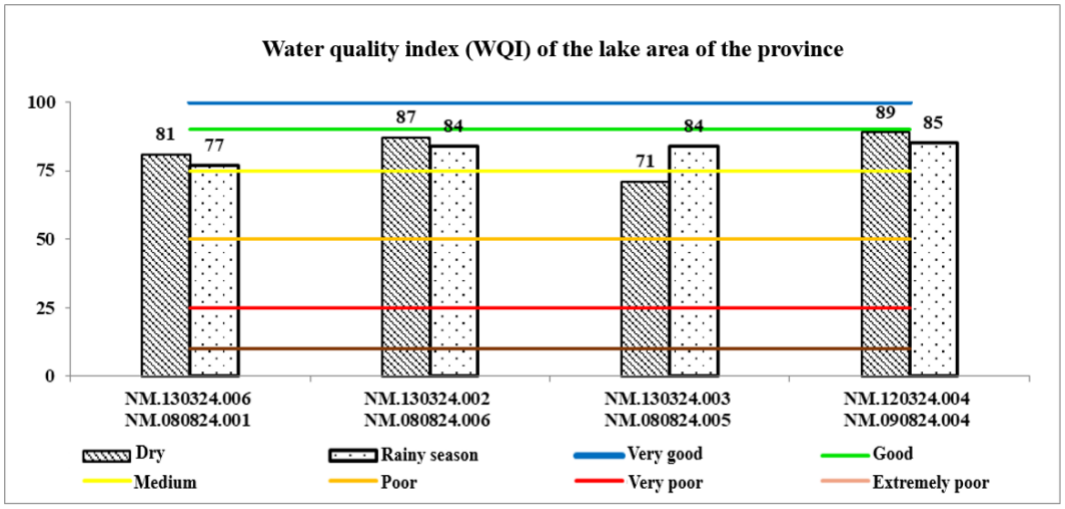

Figure 9WQI evolution of lake areas in Ben Tre province

Conclusions

The results of the analysis of parameters over the years show that the quality of surface water is fluctuating over time and shows signs of exceeding QCVN 08:2023/BTNMT. The river and canal areas flowing through Ben Tre Towns and City have quite low DO content due to the influence of rain and ebb tide; the Binh Nguyen canal area is contaminated with ammonium due to stagnation and domestic wastewater discharged by people. The port area and coastal estuaries have BOD5 and COD concentrations exceeding the standards at water quality level D. The river areas supplying water to water plants have seasonal concentrations of BOD5, ammonium, nitrite, phosphate, and nickel that all exceed the standards. It is necessary to identify the source of pollution in order to have a definitive treatment measure.

To prevent surface water pollution in Ben Tre province, it is necessary to have measures to control discharge sources from socio-economic activities, especially domestic wastewater from residential areas along rivers, ports, and estuaries; wastewater from production must be treated to meet permitted standards before being released into the environment. Agencies and sectors need to have strict control, regularly inspect compliance with environmental protection

thoroughly. Build centralized drainage and wastewater treatment systems, strengthen propaganda and education to raise people's awareness of environmental protection.

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